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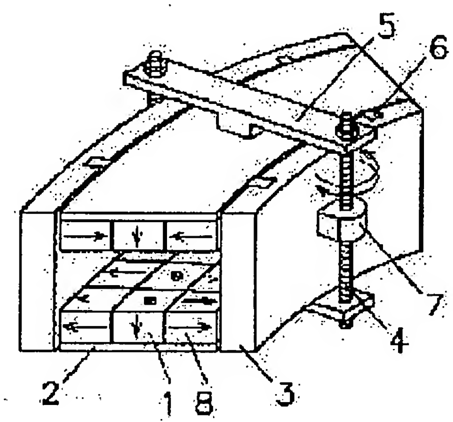
(54) PERMANENT MAGNET TYPE DEFLECTING MAGNET DEVICE AND ELECTRON STORAGE RING

(57)Abstract:
PROBLEM TO BE SOLVED: To provide a compact, simple and inexpensive permanent magnet type deflecting magnet device wherein a pair of magnet columns having a plurality of permanent magnet pieces continuously provided to array identical magnetic poles along an electron beam track are arranged in a direction for placing different magnetic poles to be opposite to each other sandwiching the electron beam track and a distance between the magnet columns.
SOLUTION: One magnet column is obtained by continuously providing a plurality of permanent magnets 1 and 8 so as to array identical magnetic poles on a base plate. Further, the other magnet column is obtained by continuously providing a plurality of permanent magnets so as to array magnetic poles difference from the above and identical magnetic poles on the base plate 2. Both of these magnetic columns are arranged by sandwiching an electron beam track and, by connecting these with a yoke 3, a magnetic field is formed. Further, both of these magnetic columns are moved by a magnetic pole driving mechanism composed of a ball screw 4, a beam 5, a linear guide 6 and a ball screw driving device 7 and thereby a distance therebetween is adjusted. Thus, an electron beam deflecting magnet device capable of easily changing a field strength is provided.



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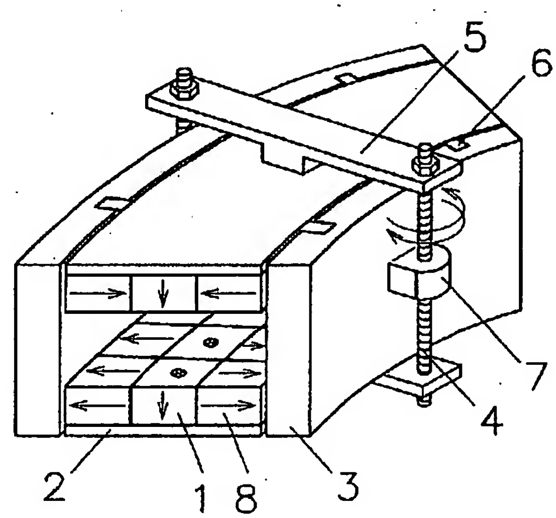
(54)【発明の名称】　永久磁石型偏向磁石装置および電子蓄積リング

(57)【要約】

【課題】　小型で低廉な電子ビーム偏向磁石装置を提供し、このような電子ビーム偏向磁石装置を組み込んだ電子蓄積リングを提供すること。

【解決手段】　電子ビーム軌道を挟んで異なる磁極が対向する向きにかつ同じ側では同じ磁極が電子ビーム軌道に沿って複数の永久磁石片1を連設した1対の磁石列と、該磁石列相互の間の距離を調整する間隙調整機構4を備えることを特徴とする永久磁石型偏向磁石装置であることを特徴とする。



【特許請求の範囲】

【請求項１】　電子ビーム軌道を挟んで異なる磁極が対向する向きにかつ同じ側では同じ磁極が並ぶように複数の永久磁石片を電子ビーム軌道に沿って連設した１対の磁石列と、該磁石列相互の間の距離を調整する間隙調整機構を備えることを特徴とする永久磁石型偏向磁石装置。

【請求項２】　異なる磁極が電子ビーム軌道を挟んで対向するように配設される永久磁石片を垂直方向に摺動可能に固定した１対のベースプレートと、該ベースプレートの端部を磁気回路的に接続するヨークと、前記ベースプレートの永久磁石片を前記ヨークに対して対称的に駆動して前記磁極間に生成される間隙を調整する磁極駆動機構を備える永久磁石型偏向磁石装置。

【請求項３】　前記電子ビーム軌道を挟んで対向する永久磁石片とヨークとの間に前記永久磁石片の磁化方向と垂直の方向に磁化された第２の永久磁石片を配設して前記磁極間間隙とヨーク中を通る磁気回路が形成されるようにしたことを特徴とする請求項２記載の永久磁石型偏向磁石装置。

【請求項４】　前記磁極駆動機構が、前記ヨークと前記ベースプレート間に設けたリニアガイドと、前記ベースプレートの一方に係合するネジと他方に係合するネジが互いに逆ネジになっているボールネジを備えて、該ボールネジの回転により前記リニアガイドの摺動方向に磁極間間隙を調整して電子ビーム軌道位置における磁場強度を調整することを特徴とする請求項１から３のいずれかに記載の永久磁石型偏向磁石装置。

【請求項５】　請求項１から４のいずれかに記載の永久磁石型偏向磁石装置を電子ビームの偏向部分に配設したことを特徴とする電子蓄積リング。

【発明の詳細な説明】

【０００１】

【発明の属する技術分野】本発明は、電子蓄積リング等のシンクロトロンを構成する電子ビーム偏向装置に関し、特に小型の自由電子レーザ装置等に使用する電子蓄積リングを形成するために有用な小型の偏向磁石装置に関する。

【０００２】

【従来の技術】電子ビームの加速や高速電子ビームの貯蔵をするため、リング状に形成された電子蓄積リングが使用される。電子蓄積リングはその目的に従って電子貯蔵リングと呼ばれることもある。電子蓄積リングは、高真空に保持したリング状の電子ビーム伝搬ラインに沿って偏向用２極磁石と収束発散用４極磁石と高周波キャビティー等を設けたもので、注入された電子群を高周波の波長間隔で並んだ電子の固まりの組にして高周波周期の整数倍の時間でリングを１周するように周回させ、電子群を高周波のピーク位置に入れて加速したり周回速度を維持するようにした高周波加速器である。

【０００３】電子蓄積リングを相対論的速度で周回する電子ビームは電子ビームの偏向位置でシンクロトロン放射を放射する。シンクロトロン放射光は、電子が磁場によって曲げられたときに軌道の接線方向に放出される電磁波であって、幅広いスペクトルと鋭い前方指向性を有し、軌道面上では殆ど水平に偏向していること等の特徴を持つ。放射光が有するこのような特徴を利用して、物性物理、化学、生物などの学問分野やリソグラフィーなどの工業分野への応用が広がっている。また、電子蓄積リング中の直線部にアンジュレータ等の挿入光源を設けて、発生する放射光を光共振器中で往復させつつ電子ビームと相互作用させて極めて鋭いスペクトル特性を有する自由電子レーザを得るようにすることができる。自由電子レーザは、一般に高出力・高効率であり、しかも発振波長がマイクロ波からＸ線領域に至る広い範囲で選択できるという特徴を有するため、医療、物性物理、新加工プロセス等、産業分野や科学技術分野に広く応用できる。

【０００４】実際に放射光や自由電子レーザを必要とする現場においてこれらを利用するためには、装置はできるだけ小型かつ低廉で取り扱いやすいものであることが要請される。従来、放射光発生装置や自由電子レーザ装置の小型化の要請に応じて、各構成要素の小型化が図られてきた。しかしそれぞれの要素の小型化には限界があり、手軽に導入できる十分に小型かつ低廉で簡便な放射光発生装置や自由電子レーザ装置を得ることが困難であった。

【０００５】これら装置の小型化・低廉化のためには、特に装置における主要な構成部である電子蓄積リングの小型化・低廉化が望まれる。しかし電子が円運動することにより発生する放射光や自由電子レーザ光の波長は電子のエネルギーに関連し、電子のエネルギーは偏向磁石の磁束密度と軌道半径に比例する。したがって、電子蓄積リングの平均径を小さくしようとすれば、偏向磁石の磁場を強くする必要がある。また、偏向部分において電子軌道に沿って発生させる磁場の強度は精密に調整する必要がある。

【０００６】従来、１．５Ｔ程度までの磁場を得るためには常電導電磁石を用いることができ、それ以上の強磁場を得るためには超電導電磁石が用いられていた。図５は、従来の４個の９０度偏向電磁石を用いた小型電子蓄積リングにおける偏向電磁石の近辺の配置例を示す平面図である。１対の４極電磁石からなる収束電磁石で運動を安定化された高エネルギー電子ビームは２個の偏向電磁石で１８０度偏向し、さらに１対の４極電磁石を通って入射と反対方向に射出する。射出された電子ビームは上記偏向電磁石と面対称に配設された２個の偏向電磁石で同様に１８０度偏向して再び図中の偏向電磁石に戻ってきて電子蓄積リングを周回する。偏向電磁石の間には電子ビームの運動を整えるために４極電磁石が設けられ

ている。
【０００７】電磁石は励磁電流により発生する磁場を制御することができるため、必要な強さの磁場を効率よく正確に発生させることができる。しかし、電磁石は磁極を巻回するコイルがあるため、電磁石同士を密着して配設することができない。また、電磁石を励磁するための電源装置を必要とする。さらに、励磁に伴う電磁石の昇温により磁極材料の磁化特性が劣化するのを防ぐ必要があり、電磁石の発熱を抑える冷却設備を備えなくてはならない。さらに、超電導電磁石を用いる場合は、強磁場を発生できるため軌道半径が小さくなるが、超電導状態を維持するために大規模な冷却装置を必要とするため、装置全体としては規模の大きな高価なものとならざるを得なかった。
【０００８】
【発明が解決しようとする課題】そこで、本発明の解決しようとする課題は、小型で低廉な電子ビーム偏向磁石装置を提供することであり、このような電子ビーム偏向磁石装置を組み込んだ電子蓄積リングを提供することにより、小型で経済的な放射光装置や自由電子レーザ装置を構成できるようにすることである。
【０００９】
【課題を解決するための手段】上記課題を解決するため、本発明の偏向磁石装置は、電子ビーム軌道を挟んで異なる磁極が対向する向きにかつ同じ側では同じ磁極が電子ビーム軌道に沿って複数の永久磁石片を連設した１対の磁石列と、該磁石列相互の間の距離を調整する間隙調整機構を備えることを特徴とする永久磁石型偏向磁石装置であることを特徴とする。本発明によれば、電磁石の代わりに永久磁石を用いるため、従来磁極の周囲を巻回していたコイルが不要になり、電子ビーム偏向装置同士を密着して配設することができる。このため、電子ビーム軌道に沿って偏向装置が占める長さが短くなりリングが小さくなる。なお、永久磁石としてはネオジム鉄ボロン（Ｎｄ－Ｆｅ－Ｂ）系磁石等、残留磁束密度が高く保磁力が大きい磁石が用いられる。また、従来の電磁石では磁界を発生させるために励磁電流を供給する必要があり、この為の電源装置や制御装置を付属させる必要があったが、永久磁石を用いたため、励磁電流が不要になり、電源装置や制御装置が省略できる。
【００１０】なお、従来、電磁石の励磁電流を調整することにより電子軌道上の磁場強度を制御していたが、本発明の偏向磁石装置では永久磁石の対向磁極間の距離を変化させて磁気回路のリラクタンスを調整することにより電子軌道における磁場の強度を制御することができる。永久磁石の位置調整は、連設される磁石片毎に行うことにより発生磁場の均質性を確保し、磁石列全体について行うことにより磁場強度の調整をする。多数の永久磁石の励磁を設計通り正確に調整することが難しく永久磁石の起磁力が小さかったことと相まって、従来永久磁石を用いた偏向磁石装置は実用に供されることがなかった。しかし、本発明の偏向磁石装置では、近年性能の向上が著しい高性能永久磁石を用い、上記のように磁極間距離を調整することにより、例えば２Ｔ程度の所望の強さを持った均質な磁場を電子ビーム軌道位置に形成させることができる。さらに、偏向装置の磁石支持部も軽量化されるため、電子ビーム軌道位置に形成する磁気回路の間隙を調整する装置も簡易なもので十分となり、偏向装置全体を経済的に構成することが可能となる。
【００１１】また、本発明の偏向磁石装置は、異なる磁極が電子ビーム軌道を挟んで対向するように配設される永久磁石片を垂直方向に摺動可能に固定した１対のベースプレートと、これらのベースプレートの端部を磁気回路的に接続するヨークと、前記ベースプレートの永久磁石片をヨークに対して対称的に駆動して永久磁石片の磁極間に生成される間隙を調整する磁極駆動機構を備えることを特徴とするものであってもよい。この発明によれば、永久磁石片とベースプレートとヨークを巡って磁極間の間隙を通る磁気回路が形成されるが、ヨークが存在するため磁気回路のリラクタンスが減少し、同じ強さの永久磁石でも電子ビーム軌道の位置に配置される間隙における磁束密度が増大する。電子ビーム軌道に沿った磁束密度の分布は個々の永久磁石の位置により調整することにより許容できる幅に収めることができる。また、永久磁石片を固定したベースプレートを磁極駆動機構で摺動させて磁極間の間隙を調整することにより、間隙に集中する磁束の密度を変化させて電子軌道位置における磁場強度を所望の値に調整することができる。
【００１２】さらに、電子ビーム軌道を挟んで対向する永久磁石片とヨークの間に第２の永久磁石片を配設して磁極間間隙とヨークを通る閉じた磁気回路が形成されるようにすることが好ましい。第２永久磁石片の起磁力が加わり磁気回路を通る磁束がより多くなるため、電子軌道位置における磁場強度が一層強くなる効果が生ずる。また、磁極駆動機構は、ヨークとベースプレート間に設けたリニアガイドと、ベースプレートの一方に係合するネジと他方に係合するネジが互いに逆ネジになっているボールネジを備えて、このボールネジの回転によりリニアガイドの摺動方向に磁極間間隙を調整して電子ビーム軌道位置における磁場強度を調整するようにすることが好ましい。このような機構を用いることにより、極く小さな力により２つの対向磁極を電子ビーム軌道を挟んで対称的に精密に動かすことができ、また調整後の位置保持も容易になる。上記の磁極駆動機構では、ステッピングモータ等の精密な駆動機を用いた精密な制御を行うことができる。
【００１３】上記課題を解決するため、本発明の電子蓄積リングは、上記の永久磁石片を用いる偏向磁石装置を電子ビームの偏向部分に配設したことを特徴とする。上記の偏向磁石装置は比較的強い磁場を形成し、必要な波

長の光を得るために要する軌道半径がより小さくなり、またコイルなどの余分なスペースを取らないので、これを用いて形成される電子蓄積リングはより小型になる。また、従来の電磁石を使用した場合と異なり、励磁電流源を要せず、また励磁に伴う発熱を抑制するための冷却装置も必要としないので、電子蓄積リング装置全体として著しく経済的に構築することが可能となる。

【００１４】

【発明の実施の形態】以下、本発明に係る偏向磁石装置および電子蓄積リングを、図面を用い実施例に基づいて詳細に説明する。図１は本発明の偏向磁石装置の実施例を示す斜視図、図２は本実施例の磁石配置を示す断面図、図３は間隙における磁場の分布を示すグラフ、図４は本発明の電子蓄積リングの平面図である。

【００１５】図１の偏向磁石装置は、第１永久磁石１、ベースプレート２、ヨーク３、ボールネジ４、梁５、リニアガイド６、ボールネジ駆動装置７、第２永久磁石８からなる。第１永久磁石１は、同じ極性の磁極が隣接して連なるようにして電子ビーム軌道に沿って配設されている。また、図２の断面図に矢印で示した磁気の向きから分かるように、第１永久磁石１の磁石列は電子ビーム軌道９の属する面に対して対称に設けられており、対向する永久磁石の対面する磁極は極性が反対になっている。ネオジムー鉄ーボロン金属間化合物微粒子を用いて一層大きな残留磁束密度と保持力を持った永久磁石が得られるようになったが、本実施例でもこのような高性能永久磁石を直列に積層した永久磁石を使用して、約２５ｍｍの磁極間間隙に約２Ｔの磁場を形成することができた。

【００１６】ベースプレート２は電子ビーム軌道面に対して対称の位置に１対設けられている。第１永久磁石１は製造過程で生ずる磁化強度の差を吸収して電子ビーム軌道位置に生じる磁場の強度を均質にするため対向する第１永久磁石との間隔を個々に調整した上で、ベースプレート２に固定される。ヨーク３はケイ素鋼等の軟磁性材料からなり、上記１対のベースプレート２の端部を磁気的に接続して磁気回路のリラクタンスを低下させ、ギャップにおける磁束密度を高める効果を有する。ヨーク３が存在することによりギャップにおける磁場強度は約１０％強化されることが分かった。なお、偏向磁石装置の外周側に設けられるヨーク３には放射光を取り出すための孔がいくつか開けられている。

【００１７】ボールネジ４は、１対が偏向磁石装置のほぼ中央位置でヨーク３の外側に垂直に設けられている。ボールネジ４には上端部と下端部で反対向きのピッチの細かい雄ネジが切ってあって、雄ネジが上下１対のベースプレート２にそれぞれ固定された１対の梁５の両端部に設けられた雌ねじにそれぞれ係合している。したがって、１対のボールネジ４を同時に同じ方向に同じ速度で回転させると、上下のベースプレート２が平行を保持しながら相互に対称的に移動して第１永久磁石の磁極面の距離が微少に精度よく変化するようになっている。なお、ボールネジ４の雄ネジの向きによっては、１対のボールネジ４を逆方向に回転駆動することにより、ベースプレート２の間隔制御をするように構成することもできる。

【００１８】１対のボールネジ駆動装置７がそれぞれヨーク３の外側中央に固定されていて、それぞれボールネジ４のほぼ中央部で係合して、上記１対のボールネジ４を同時に同じ量だけ回転させる。本実施例のボールネジ駆動装置７では、制御部から同じパルス信号を発生させてステッピングモータを制御することにより、二つのボールネジ４を精密に回転させるようにしている。また、ベースプレート２が円滑にかつ電子ビーム軌道面に対して正確な垂直方向に動くようにするため、ヨーク３とベースプレート２の摺動面にリニアガイド６がボールネジ４と平行に適当数敷設されている。第２永久磁石は、第１永久磁石１と同じような高性能磁気材料で形成された永久磁石であり、第１永久磁石１の磁極間間隙における磁場強度を補強するために第１永久磁石１とヨーク３の間に、磁極の向きが磁気回路の磁束の向きに合うように布設されている。大型の永久磁石が必要なときには小型に成型したものを直列に積層して用いてもよい。

【００１９】本実施例に係る偏向磁石装置により、第１永久磁石１の磁極面の幅を８０ｍｍとし、磁極間距離を約２５ｍｍとするときに、ギャップ中央の電子ビーム軌道面内において電子ビームに垂直な方向に５０ｍｍにわたって２．０６Ｔ程度の平坦な磁場強度を生成させることができた。なお、ヨーク３を撤去して電子ビーム軌道の両脇を解放する場合にも、約１．９３Ｔの磁場強度を達成することができる。図３は偏向磁石装置のギャップにおける磁場分布を示すグラフで、横軸に第１永久磁石の中心軸からの距離、縦軸にギャップにおける磁場強度をそれぞれ任意スケールで表したものである。実線で表したものがヨークを備えた状態、点線がヨークの無い場合を表している。このように本実施例では約２Ｔの磁場強度を得ることができるから、電子軌道に沿って磁束密度を測定しながら個々の磁石毎に磁石面位置を調整して磁場強度分布を均質化し、さらに磁極間距離を調整して所望の磁場強度を得るようにすることができる。

【００２０】図４は上記実施例の偏向磁石装置を使用して構成した小型の電子蓄積リングを表す平面図である。電子蓄積リングは、図中左の端部に電子ビームを９０度偏向する偏向磁石装置２２、２４を密接して組み合わせて電子を１８０度偏向させるようにした偏向磁石装置を、また右の端部に同じ偏向磁石装置２６、２８を密接して設け、それら偏向磁石装置間の直線部にセプタムマグネット４２とＲＦキャビティ４４とキッカーマグネット４６を備えている。なお、電子蓄積リング両端の偏向磁石装置の上流と下流にはそれぞれＱマグネット３０の

セットを付設して電子ビームの質を確保するようにしている。

【００２１】この電子蓄積リングには高エネルギーの電子を発生する電子入射器１０が付設されている。電子入射器１０から射出される電子ビームは小型の偏向磁石装置１２により９０度偏向して、セプタムマグネット４２を介して電子蓄積リングに注入される。注入された電子ビームはキッカーマグネット４６の働きにより電子蓄積リングを周回する電子ビームと合体する。電子ビームは偏向磁石装置２２、２４、２６、２８で電子軌道の接線方向に放射光を放出するので、この放射光を利用することができる。電子蓄積リング中を周回している間に電子が失うエネルギーはＲＦキャビティ４４で補充する。なお、電子蓄積リングの直線部に挿入光源を備えて、放出される光を利用することもできる。上記のように構成することによって、短軸方向の外径約２ｍ、長軸方向の外径約４．８ｍの極めて小型の電子蓄積リングとすることができる。

【００２２】なお、本実施例の説明において、偏向磁石装置の偏向角度を９０度としたが、この値は任意に選択できることは言うまでもない。また、第１永久磁石の磁極間隔を調整するため、永久磁石を固定したベースプレート全体の位置調整を行う方法について記載したが、ベースプレートと独立して永久磁石部分のみを駆動して間隙調整するようにしてもよい。また、本発明の偏向磁石装置はコイルのはみ出しや冷却装置を不要とし互いに密接して一体に設置することができるが、間に４極電磁石や６極電磁石を挿入して、ビームの質を向上させるようにしてもよい。さらに、本実施例の説明では偏向磁石装置を電子蓄積リングに使用した態様について取り上げたが、本発明の偏向磁石装置は陽電子蓄積リングはもとより要し等の荷電粒子を扱うシンクロトロン全般に適用できることはいうまでもない。

【００２３】

【発明の効果】以上詳細に説明した通り、本発明の偏向磁石装置は電磁石型と比較して小型にすることができ、コイルや冷却装置などを必要としないため磁場ギャップの制御のために用いる小さな電源以外に電源を必要とせず、偏向磁石と偏向磁石の間の空間を有効に利用することができるため、小型の電子蓄積リングを経済的に構成することができる。

【図面の簡単な説明】

【図１】本発明の本発明の偏向磁石装置の実施例を示す斜視図である。

【図２】本実施例の磁石配置を示す断面図である。

【図３】本実施例の磁極間間隙における磁場の分布を示すグラフ図である。

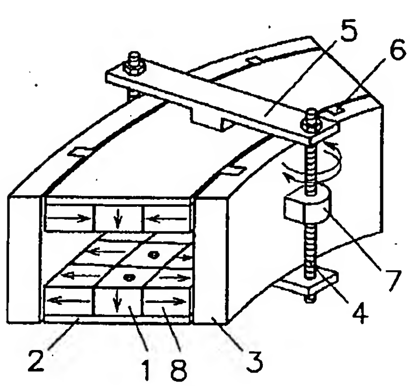
【図４】本発明の電子蓄積リングの配置図である。

【図５】従来の小型電子蓄積リングの偏向電磁石部分の配置図である。

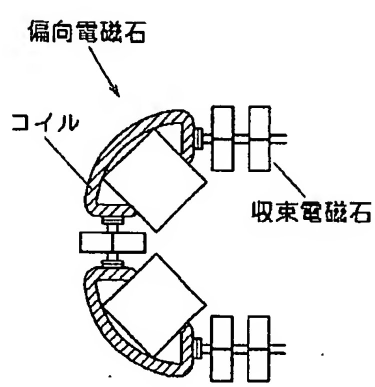
【符号の説明】

１　永久磁石
２　ベースプレート
３　ヨーク
４　ボールネジ
５　梁
６　リニアガイド
７　ボールネジ駆動装置
８　永久磁石
９　電子ビーム軌道
１０　電子入射器
１２、２２、２４、２６、２８　偏向磁石装置
３０　Ｑマグネット
４２　セプタムマグネット
４４　ＲＦキャビティ
４６　チェッカーマグネット

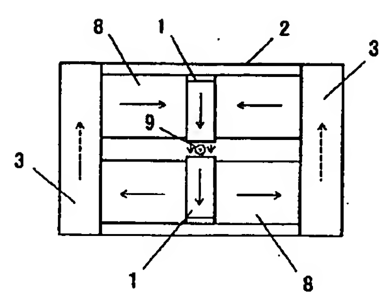
【図１】



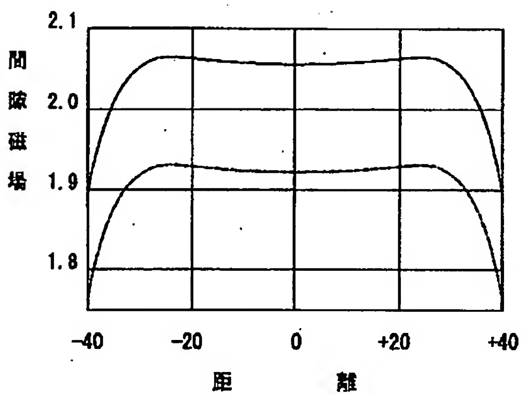
【図５】



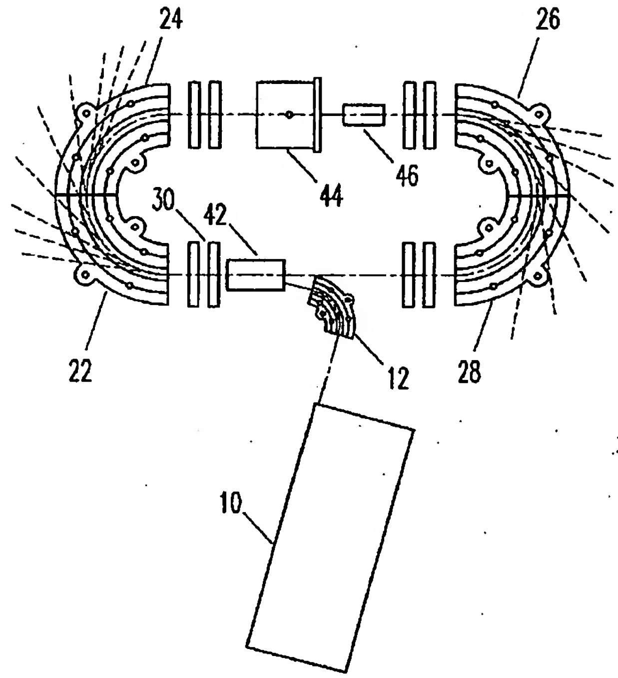
【図２】



【図３】



【図４】



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[Translation done.]

Epitome

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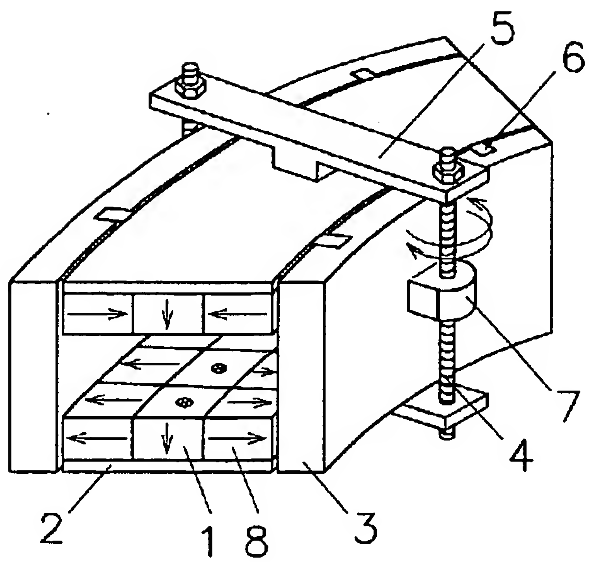
(57) [Abstract]
[Technical problem] Offer a small and cheap electron beam deviation magnet system, and offer the electronic storage rings incorporating such an electron beam deviation magnet system.
[Means for Solution] It is characterized by being the permanent-magnet type deviation magnet system characterized by having the gap adjustment device 4 in which one pair of magnet trains in which were turned to, and were resembled and the magnetic pole same in the same side which a different magnetic pole on both sides of an electron beam orbit counters formed successively two or more pieces 1 of a permanent magnet in accordance with the electron beam orbit, and the distance between these both magnet trains are adjusted.

[Translation done.]



[Translation done.]

* NOTICES *

CLAIMS

[Claim(s)]
[Claim 1] The permanent-magnet type deviation magnet system characterized by having the gap adjustment device in which one pair of magnet trains which formed successively two or more pieces of a permanent magnet in accordance with the electron beam orbit so that it was suitable, and it might be alike and the magnetic pole same in the same side which a different magnetic pole on both sides of an electron beam orbit counters might be located in a line, and the distance between these both magnet trains are adjusted.
[Claim 2] A permanent-magnet type deviation magnet system equipped with the magnetic pole drive which adjusts York which connects the edge of this base plate with one pair of base plates which fixed the piece of a

permanent magnet arranged so that a different magnetic pole may counter on both sides of an electron beam orbit possible [sliding of a perpendicular direction] in magnetic circuit, and the gap which drives symmetrically the piece of a permanent magnet of said base plate to said York, and is generated between said magnetic poles.
[Claim 3] The permanent-magnet type deviation magnet system according to claim 2 characterized by forming the magnetic circuit which arranges the magnetization direction [of said piece of a permanent magnet], and 2nd piece of a permanent magnet which were magnetized in the perpendicular direction between the pieces of a permanent magnet and York which counter on both sides of said electron beam orbit, and passes along the inside of the gap between said magnetic poles, and York.
[Claim 4] A permanent-magnet type deviation magnet system given in either of claims 1-3 characterized by to equip said magnetic pole drive with the ball screw with which said York and linear guide prepared between said base plates, the screw with which it engages with one side of said base plate, and the screw which engages with another side are a reverse screw mutually, and for rotation of this ball screw to adjust the gap between magnetic poles in the sliding direction of said linear guide, and to adjust the magnetic field strength in an electron beam orbital position.
[Claim 5] Electronic storage rings characterized by arranging a permanent-magnet type deviation magnet system given in either of claims 1-4 in the deviation part of an electron beam.

[Translation done.]

DETAILED DESCRIPTION

[Detailed Description of the Invention]
[0001]

[Field of the Invention] This invention relates to a useful small deviation magnet system, in order to form the electronic storage rings especially used for small free electron laser equipment etc. about the electron beam deviation equipment which constitutes synchrotrons, such as electronic storage rings.
[0002]
[Description of the Prior Art] In order to carry out acceleration of an electron beam, and storage of a high-speed electron beam, the electronic storage rings formed in the shape of a ring are used. Electronic storage rings may be called an electronic storage ring according to the purpose. Electronic storage rings are what prepared 2 pole magnet for a deviation, 4 pole magnet for convergence emission, the high frequency mold cavity, etc. along electron beam propagation Rhine of the shape of a ring held to the high vacuum. It is the RF accelerator which was made to go around so that the poured-in electronic group may be made into the group of the lump of the electron located in a line at intervals of the wavelength of a RF and a ring may be carried out 1 round by the time amount of the integral multiple of a RF period, put the electronic group into the peak location of a RF, and accelerated, or maintained the circumference rate.
[0003] The electron beam which goes electronic storage rings around at a relativistic rate emits synchrotron radiation in the deviation location of an electron beam. Synchrotron radiation is an electromagnetic wave emitted to an orbital tangential direction, when an electron is bent by the magnetic field, has a broad spectrum and sharp front directivity, and has the descriptions, such as deflecting almost at a horizontal, on an orbital plane. The application to the industrial fields, such as the learning fields, such as condensed matter physics, chemistry, and a living thing, and lithography, has spread using such a description that synchrotron orbital radiation has. Moreover, the free electron laser which is made to carry out an interaction to an electron beam, and has very sharp spectral characteristics can be obtained, preparing the insertion light sources, such as undulater, in the bay in electronic storage rings, and making the synchrotron orbital radiation to generate go in an optical resonator. Since a free electron laser has the description that it is efficient and generally oscillation wavelength can moreover choose in high power and the large range from microwave to an X-ray field, it is widely applicable to a field industrial [, such as medicine, condensed matter physics, and a new processing process,] or a scientific and research discipline.
[0004] In order to use these in the site which actually needs synchrotron orbital radiation and a free electron laser, to be what

equipment is small and cheap as much as possible, and it is easy to deal with is demanded. Conventionally, the miniaturization of each component has been attained according to the request of a miniaturization of a synchrotron orbital radiation generator or free electron laser equipment. However, it was difficult to obtain the synchrotron orbital radiation generator small enough and cheap, and simple which there is a limitation in the miniaturization of each element and can be introduced easily, and free electron laser equipment.

[0005] Especially for a miniaturization and cheap-izing of these equipments, a miniaturization and cheap-ization of the electronic storage rings which are the main configuration sections in equipment are desired. However, in the wavelength of the synchrotron orbital radiation generated when an electron moves circularly, or a free electron laser beam, in relation to electronic energy, electronic energy is proportional to the flux density and the orbital radius of a deviation magnet. Therefore, if it is going to make the pitch diameter of electronic storage rings small, it is necessary to strengthen the magnetic field of a deviation magnet. Moreover, it is necessary to adjust the reinforcement of the magnetic field generated along an electron orbit in a deviation part to a precision.

[0006] In order to obtain the magnetic field to about 1.5T conventionally, the usual state electrical conduction electromagnet could be used, and the superconduction electromagnet was used in order to obtain the strong magnetic field beyond it. Drawing 5 is the top view showing the neighboring example of arrangement of the deviation electromagnet in the small electronic storage rings which used the conventional four 90-degree deviation electromagnet. The high energy electron beam which had movement stabilized with the convergence electromagnet which consists of a 1 to 4 pole electromagnet is deflected 180 degrees with two deviation electromagnets, and is injected to incidence and an opposite direction through a further 1 to 4 pole electromagnet. The injected electron beam is similarly deflected 180 degrees with the above-mentioned deviation electromagnet and two deviation electromagnets arranged by the field symmetry, returns to the deviation electromagnet in drawing again, and goes electronic storage rings around. Between deviation electromagnets, in order to prepare movement of an electron beam, 4 pole electromagnet is formed.

[0007] Since an electromagnet can control the magnetic field generated according to an exciting current, it can generate the magnetic field of required strength correctly efficiently. However, since an electromagnet has the coil which winds a magnetic pole, it cannot stick and arrange

electromagnets. Moreover, the power unit for exciting an electromagnet is needed. Furthermore, it is necessary to prevent the magnetization property of a magnetic pole ingredient deteriorating according to the temperature up of the electromagnet accompanying excitation, and must have the cooling equipment which suppresses generation of heat of an electromagnet. Furthermore, when a superconduction electromagnet was used, since a strong magnetic field was generated, the orbital radius became small, but since a cooling system large-scale in order to maintain a superconducting state was needed, as the whole equipment, it could not but become the expensive big thing of a scale.

[0008]

[Problem(s) to be Solved by the Invention] Then, the technical problem which is going to solve this invention is offering a small and cheap electron beam deviation magnet system, and is enabling it to constitute small and economical synchrotron orbital radiation equipment and free electron laser equipment by offering the electronic storage rings incorporating such an electron beam deviation magnet system.

[0009]

[Means for Solving the Problem] It is characterized by to be the permanent-magnet type deviation magnet system characterized by to equip the deviation magnet system of this invention with the gap adjustment device in_which one pair of magnet trains in which were turned to, and were resembled and the magnetic pole same in the same side which a different magnetic pole on both sides of an electron beam orbit counters formed successively two or more pieces of a permanent magnet in accordance with the electron beam orbit, and the distance between these both magnet trains are adjusted in order to solve the above-mentioned technical problem. According to this invention, since a permanent magnet is used instead of an electromagnet, the coil which was winding the perimeter of a magnetic pole conventionally becomes unnecessary, and can stick and arrange electron beam deviation equipments. For this reason, the die length which deviation equipment occupies in accordance with an electron beam orbit becomes short, and a ring becomes small. In addition, as a permanent magnet, magnets with large coercive force with a high residual magnetic flux density, such as a neodymium iron boron (Nd-Fe-B) system magnet, are used. Moreover, with the conventional electromagnet, in order to generate a field, the exciting current needed to be supplied, the power unit and control unit for it needed to be attached, but since the permanent magnet was used, an exciting current becomes unnecessary and a power unit and a control unit can be omitted.

[0010] In addition, although the magnetic field strength on an electron

orbit was controlled by adjusting the exciting current of an electromagnet conventionally, the reinforcement of the magnetic field in an electron orbit is controllable by the deviation magnet system of this invention by changing the distance between the opposite magnetic poles of a permanent magnet, and adjusting the reluctance of a magnetic circuit. By carrying out for every piece of the magnet formed successively, justification of a permanent magnet secures the homogeneity of a generating magnetic field, and adjusts magnetic field strength by carrying out about the whole magnet train. Practical use was not presented with that it is difficult to adjust excitation of many permanent magnets to accuracy as a design, and the magnetomotive force of a permanent magnet was small, and the deviation magnet system using the permanent magnet conventionally conjointly. However, a homogeneous magnetic field with the strength of a request of an about [2T] can be made to form in an electron beam orbital position in the deviation magnet system of this invention, when improvement in the engine performance adjusts the distance between magnetic poles as mentioned above in recent years using a remarkable high performance permanent magnet. Furthermore, the magnet supporter of deviation equipment and the equipment which adjusts the gap of the magnetic circuit formed in an electron beam orbital position since it is lightweight-ized are simple, and becomes possible [constituting a next door and the whole deviation equipment economically enough].

[0011] Moreover, the deviation magnet system of this invention may be characterized by to have the magnetic pole drive which adjusts York which connects the edge of these base plates with one pair of base plates which fixed the piece of a permanent magnet arranged so that a different magnetic pole may counter on both sides of an electron beam orbit possible [sliding of a perpendicular direction] in magnetic circuit, and the gap which drives symmetrically the piece of a permanent magnet of said base plate to York, and is generated between the magnetic poles of the piece of a permanent magnet. According to this invention, the magnetic circuit which passes along the gap between magnetic poles involving the piece of a permanent magnet, a base plate, and York is formed, but since York exists, the reluctance of a magnetic circuit decreases, and the flux density in the gap in which the permanent magnet of the same strength is also arranged in the location of an electron beam orbit increases. Distribution of the flux density in alignment with an electron beam orbit can be stored in width of face permissible by adjusting with the location of each permanent magnet. Moreover, by sliding the base plate which fixed the piece of a permanent magnet with

a magnetic pole drive, and adjusting the gap between magnetic poles, the consistency of the magnetic flux concentrated on a gap can be changed, and the magnetic field strength in an electron orbit location can be adjusted to a desired value.

[0012] Furthermore, it is desirable that the closed magnetic circuit which arranges the 2nd piece of a permanent magnet between the piece of a permanent magnet which counters on both sides of an electron beam orbit, and York, and passes along the gap between magnetic poles and York is formed. Since the magnetic flux which the magnetomotive force of the piece of the 2nd permanent magnet is added, and passes along a magnetic circuit increases more, the effectiveness that the magnetic field strength in an electron orbit location becomes still stronger arises. Moreover, as for a magnetic pole drive, it is desirable to have the ball screw with which York, the linear guide prepared between base plates, the screw which engages with one side of a base plate, and the screw which engages with another side are a reverse screw mutually, and for rotation of this ball screw to adjust the gap between magnetic poles in the sliding direction of a linear guide, and to adjust the magnetic field strength in an electron beam orbital position. By using such a device, two opposite magnetic poles can be symmetrically moved to a precision on both sides of an electron beam orbit by ************, and the station keeping after adjustment also becomes easy. In the above-mentioned magnetic pole drive, precise control using precise drivers, such as a stepping motor, can be performed.

[0013] In order to solve the above-mentioned technical problem, the electronic storage rings of this invention are characterized by arranging in the deviation part of an electron beam the deviation magnet system which uses the above-mentioned piece of a permanent magnet. Since the above-mentioned deviation magnet system forms a comparatively strong magnetic field, and the orbital radius required in order to obtain the light of required wavelength becomes smaller and excessive tooth spaces, such as a coil, are not taken, the electronic storage rings formed using this become small more. Moreover, since the cooling system for unlike the case where the conventional electromagnet is used not requiring an excitation current source and controlling generation of heat accompanying excitation is not needed, either, it becomes possible to build remarkably economically as the whole electronic storage-rings equipment.

[0014]

[Embodiment of the Invention] Hereafter, the deviation magnet system and electronic storage rings concerning this invention are explained to a

detail based on an example using a drawing. The perspective view in which drawing 1 shows the example of the deviation magnet system of this invention, the sectional view in which drawing 2 shows magnet arrangement of this example, the graph which shows distribution of a magnetic field [in / in drawing 3 / a gap], and drawing 4 are the top views of the electronic storage rings of this invention.

[0015] The deviation magnet system of drawing 1 consists of the 1st permanent magnet 1, a base plate 2, York 3, a ball screw 4, a beam 5, the linear guide 6, a ball screw driving gear 7, and the 2nd permanent magnet 8. As the same polar magnetic pole adjoins and the 1st permanent magnet 1 stands in a row, it is arranged in accordance with the electron beam orbit. Moreover, the magnet train of the 1st permanent magnet 1 is prepared in the symmetry to the field where the electron beam orbit 9 belongs, and, as for the magnetic pole which the permanent magnet which counters meets, the polarity is opposite so that the sense of the MAG shown in the sectional view of drawing 2 by the arrow head may show. Although the permanent magnet which had much more big residual magnetic flux density and holding power using the neodymium-iron-boron intermetallic-compound particle came to be obtained, this example was also able to use the permanent magnet which carried out the laminating of such a high performance permanent magnet to the serial, and was able to form the magnetic field of about 2 T in the gap between [of about 25mm] magnetic poles.

[0016] One pair of base plate 2 is formed in the location of the symmetry to the electron beam orbital plane. The 1st permanent magnet 1 is fixed to a base plate 2 after adjusting separately spacing with the 1st permanent magnet which counters in order to make into homogeneity reinforcement of the magnetic field which absorbs the difference of magnetization intensity produced in a manufacture process, and is produced in an electron beam orbital position. York 3 consists of soft magnetic materials, such as ferrosilicon, the edge of the one above-mentioned pair of base plates 2 is connected magnetically, the reluctance of a magnetic circuit is reduced, and it has the effectiveness which raises the flux density in a gap. When York 3 exists showed that the magnetic field strength in a gap was strengthened about 10%. In addition, some holes for taking out synchrotron orbital radiation have opened in York 3 established in the periphery side of a deviation magnet system.

[0017] As for the ball screw 4, the deviation magnet system is mostly formed for one pair at right angles to the outside in York 3 with the mid gear. To the ball screw 4, the male screw with the fine pitch of the

opposite sense is turned off by the upper limit section and the lower limit section, and the male screw is engaging with the female screw formed in the both ends of one pair of beams 5 fixed to the base plate 2 of one pair of upper and lower sides, respectively, respectively. Therefore, if one pair of ball screws 4 are rotated at the same rate as the same direction as coincidence, while the up-and-down base plate 2 holds parallel, it will move mutually symmetrically and the distance of the pole face of the 1st permanent magnet will change with a sufficient precision very small. In addition, by carrying out the rotation drive of one pair of ball screws 4 to hard flow depending on the sense of the male screw of a ball screw 4, it can also constitute so that spacing control of a base plate 2 may be carried out.

[0018] one pair of ball screw driving gears 7 are fixed in the center of an outside in York 3, respectively -- having -- **** -- respectively -- a ball screw 4 -- it is mostly engaged in the center section and only the same amount as coincidence rotates the one above-mentioned pair of ball screws 4. He is trying to make a precision rotate two ball screws 4 by generating the same pulse signal from a control section, and controlling a stepping motor by the ball screw driving gear 7 of this example. Moreover, in order to make it a base plate 2 move to an exact perpendicular direction to an electron beam orbital plane smoothly, the linear guide 6 is suitable-number-laid in parallel with a ball screw 4 by the sliding surface of York 3 and a base plate 2. The 2nd permanent magnet is a permanent magnet formed with the same high performance magnetic adjuster as the 1st permanent magnet 1, and in order to reinforce the magnetic field strength in the gap between magnetic poles of the 1st permanent magnet 1, it is laid so that the sense of a magnetic pole may suit the sense of the magnetic flux of a magnetic circuit between the 1st permanent magnet 1 and York 3. The laminating of the thing whose large-sized permanent magnet is the need and which was occasionally cast small may be carried out to a serial, and it may be used for it.

[0019] When setting width of face of the pole face of the 1st permanent magnet 1 to 80mm and setting distance between magnetic poles to about 25mm with the deviation magnet system concerning this example, 50mm was able to be made to generate about [2.06T] flat magnetic field strength covering a direction perpendicular to an electron beam in the electron beam orbital plane of the center of a gap. In addition, also when removing York 3 and releasing both the sides of an electron beam orbit, the magnetic field strength of about 1.93 T can be attained. Drawing 3 is the graph which shows the magnetic field distribution in the gap of a

deviation magnet system, and expresses magnetic field strength [in / in / to the distance from the medial axis of the 1st permanent magnet / an axis of abscissa / to an axis of ordinate / a gap] with an arbitration scale, respectively. The case where York does not have the condition and dotted line with which what was expressed with the continuous line was equipped with York is expressed. Thus, in this example, since the magnetic field strength of about 2 T can be obtained, measuring flux density along an electron orbit, a magnet side location is adjusted for each magnet of every, magnetic-field-strength distribution is homogenized, the distance between magnetic poles is adjusted further, and desired magnetic field strength can be obtained.

[0020] Drawing 4 is a top view showing the small electronic storage rings constituted using the deviation magnet system of the above-mentioned example. Electronic storage rings were close in the deviation magnet systems 26 and 28 same again as a right edge, formed the deviation magnet system it is [magnet system] close to the edge of ******, combine [magnet system] with it the deviation magnet systems 22 and 24 which deflect an electron beam 90 degrees, and it was made to deflect an electron 180 degrees, and equip the bay between these deviation magnet systems with the septum magnet 42, the RF cavity 44, and the kicker magnet 46. In addition, he attaches the set of the Q magnet 30 to the upstream and the lower stream of a river of a deviation magnet system of electronic storage-rings both ends, respectively, and is trying to secure the quality of an electron beam.

[0021] The electronic injector 10 which generates the electron of high energy is attached to these electronic storage rings. The electron beam injected from the electronic injector 10 is deflected 90 degrees with the small deviation magnet system 12, and is poured into electronic storage rings through the septum magnet 42. The poured-in electron beam coalesces in the electron beam which goes electronic storage rings around by work of the kicker magnet 46. Since an electron beam emits synchrotron orbital radiation to the tangential direction of an electron orbit with the deviation magnet systems 22, 24, 26, and 28, this synchrotron orbital radiation can be used. While going in electronic storage rings around, the energy which an electron loses is replaced with the RF cavity 44. In addition, the bay of electronic storage rings can be equipped with the insertion light source, and the light emitted can also be used. By constituting as mentioned above, it can consider as very small electronic storage rings with an outer diameter [of the direction of a minor axis / of about 2m], and an outer diameter [of the direction of a major axis] of about 4.8m.

[0022] In addition, in explanation of this example, although the deflecting angle of a deviation magnet system was made into 90 degrees, it cannot be overemphasized that this value can be chosen as arbitration. Moreover, although how to justify the whole base plate which fixed the permanent magnet was indicated in order to adjust magnetic pole spacing of the 1st permanent magnet, only a permanent magnet part is driven independently with a base plate, and it may be made to carry out gap adjustment. Moreover, although the deviation magnet system of this invention presupposes that it is unnecessary, is mutually close and can install the flash and cooling system of a coil in one, it inserts 4 pole electromagnet and 6 pole electromagnet in between, and you may make it raise the quality of a beam. furthermore, the voice which used the deviation magnet system for electronic storage rings in explanation of this example -- although it attached like and being taken up -- the deviation magnet system of this invention -- positive electron storage rings -- from the first -- requiring -- etc. -- it cannot be overemphasized that it is applicable to a synchrotron at large [treating a charged particle].

[0023]

[Effect of the Invention] Since the deviation magnet system of this invention can be made small as compared with an electromagnet mold, and it does not need a power source other than the small power source used for control of a magnetic field gap since it needs neither a coil nor a cooling system but the space between a deviation magnet and a deviation magnet can be effectively used as explained to the detail above, small electronic storage rings can be constituted economically.

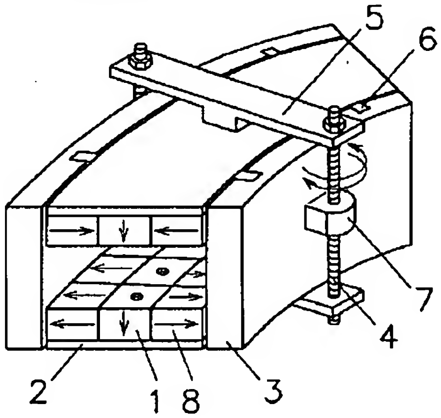
[Translation done.]

DESCRIPTION OF DRAWINGS

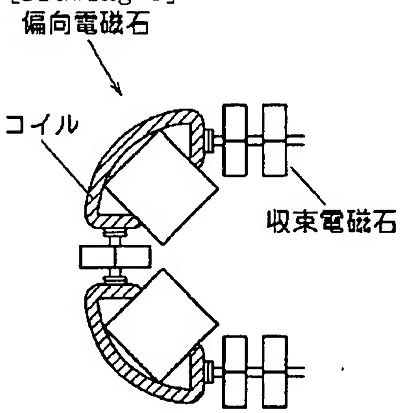
[Brief Description of the Drawings]
[Drawing 1] It is the perspective view showing the example of the deviation magnet system of this invention of this invention.
[Drawing 2] It is the sectional view showing magnet arrangement of this example.
[Drawing 3] It is the graphical representation showing distribution of the magnetic field in the gap between magnetic poles of this example.
[Drawing 4] It is the plot plan of the electronic storage rings of this invention.
[Drawing 5] It is the plot plan of the deviation electromagnet part of the conventional small electronic storage rings.
[Description of Notations]
1 Permanent Magnet
2 Base Plate
3 York
4 Ball Screw
5 Beam
6 Linear Guide
7 Ball Screw Driving Gear
8 Permanent Magnet
9 Electron Beam Orbit
10 Electronic Injector
12, 22, 24, 26, 28 Deviation magnet system
30 Q Magnet
42 Septum Magnet
44 RF Cavity
46 Checkered Magnet

DRAWINGS

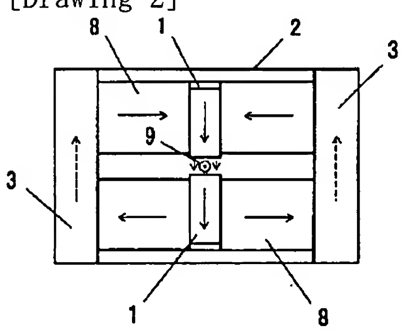
[Drawing 1]



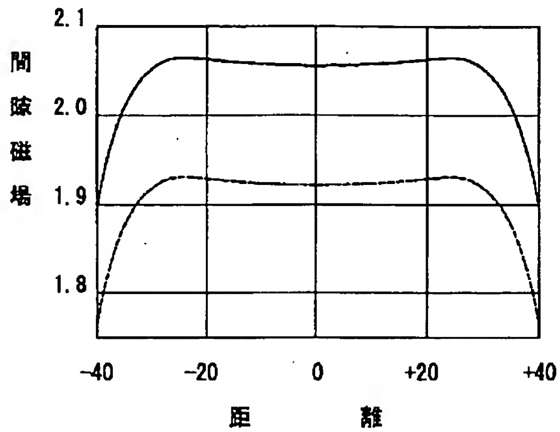
[Drawing 5]



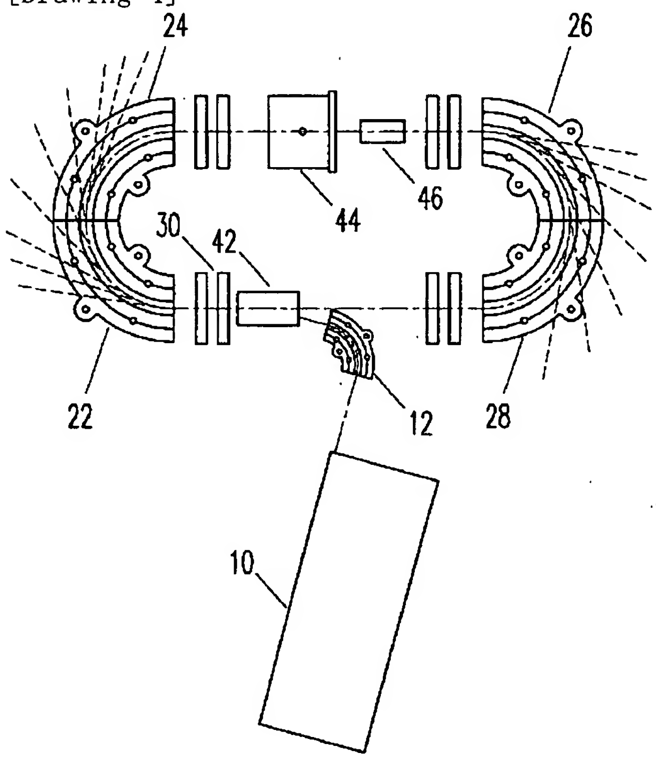
[Drawing 2]



[Drawing 3]



[Drawing 4]



[Translation done.]